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PROGRAM FOR THE DESIGN OF AN AXIAL COMPRESSOR STAGE
BASED ON THE RADIAL EQUILIBRIUM EQUATIONS

by

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Abstract:

A computer program is presented to determine the three-dimensional flow conditions in an axial flow compressor stage. Entropy and energy gradients are taken into account as well as the radial shift and the curvatures of the axisymmetric stream surfaces. The program can be used at elevated Mach numbers since shock losses and compressibility effects are included. It represents an extension of work done for a research program to investigate the tip clearance effects in a three-stage compressor, supported by:

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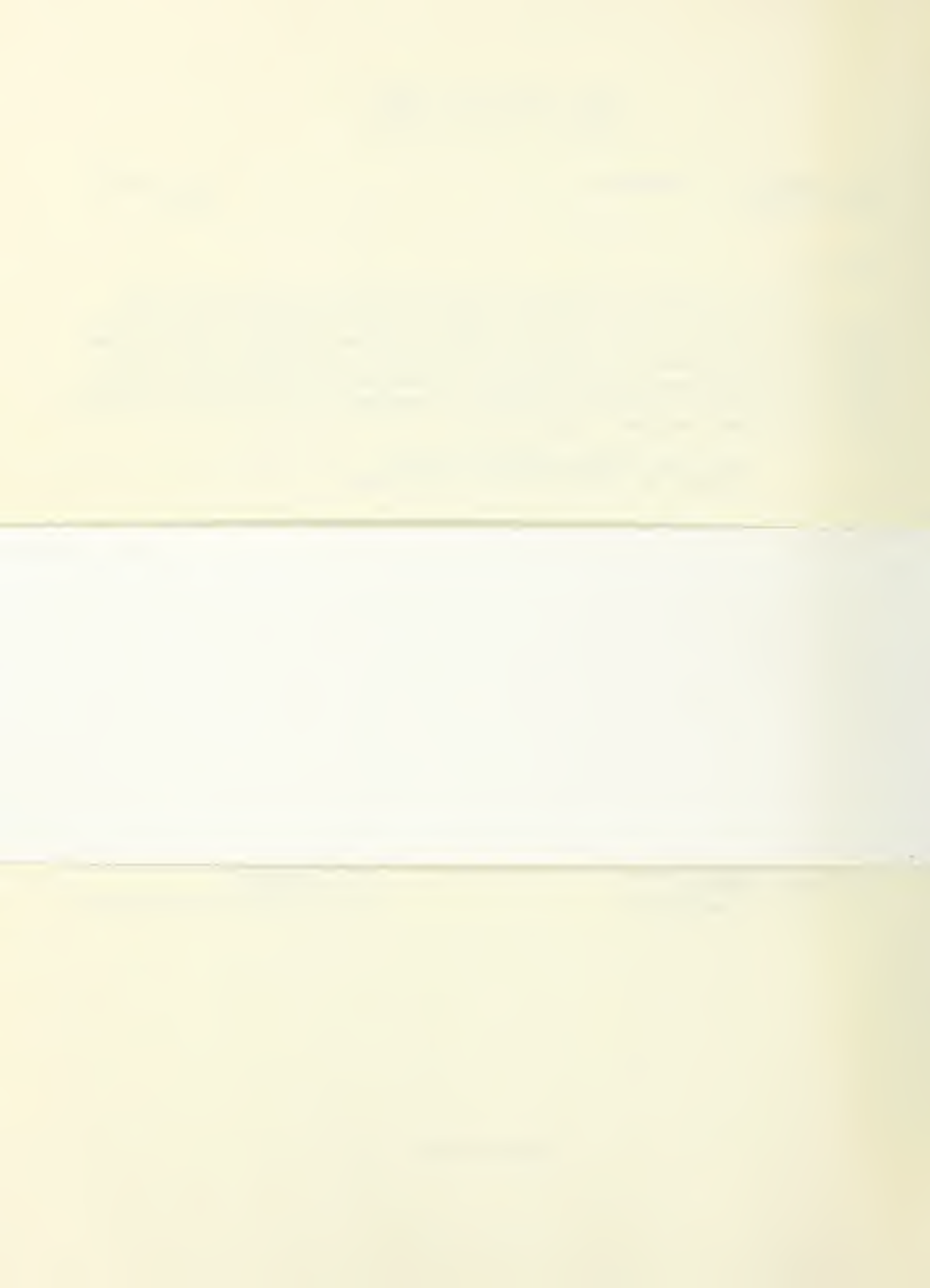


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BASED ON THE RADIAL EQUILIBRIUM EQUATIONS

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Kyriacos D. Papailiou

1. Introduction

The present report describes a program which has been established for the design of an axial flow compressor intermediate stage using the radial equilibrium equations as described in ref. 1 (pages 439 - 454). An intermediate stage is defined as one for which inlet and outlet velocities are essentially the same.

The flow is assumed compressible and axisymmetric. The inlet conditions, some of which are data to the program, are assumed to have been produced in preceding stages and are referred to ambient conditions). Energy gradients at the inlet, which may be caused by non-uniform energy addition in previous stages, as well as entropy gradients at the inlet, which may be due to non-uniform energy dissipation in previous stages, are taken into account.

The losses and the corresponding entropy increase through the rotor and the stator are calculated according to reference 3, and non-uniform energy increase in the rotor can be specified.

The inner and outer walls may have arbitrary shape. However, when the curvature of the streamlines (in the way described in reference 1.) is taken into account, then the inner and outer walls, although maybe tapered, have to be straight.

The problem is considered from the designer's point of view. Consequently, specified will be the work distribution, and the quantity $\frac{Vu_1 + Vu_2}{u_1 + u_2}$ will be specified along the radius (see symbol table for symbols). The quantity $\frac{Vu_1 + Vu_2}{u_1 + u_2}$ gives the theoretical reaction factor for an intermediate stage with constant axial velocity for incompressible flow. This quantity was chosen instead of the actual reaction factor as the expression



of the actual reaction factor is rather involved in the general case (see Appendix A). The thermodynamic diagram of the process through the stage is given in Figure (1) while the general layout is given in Figure (2).

In the following the theory will first be developed and then the program will be described. Symbols are defined in the symbol table and the FORTRAN Symbol Table.

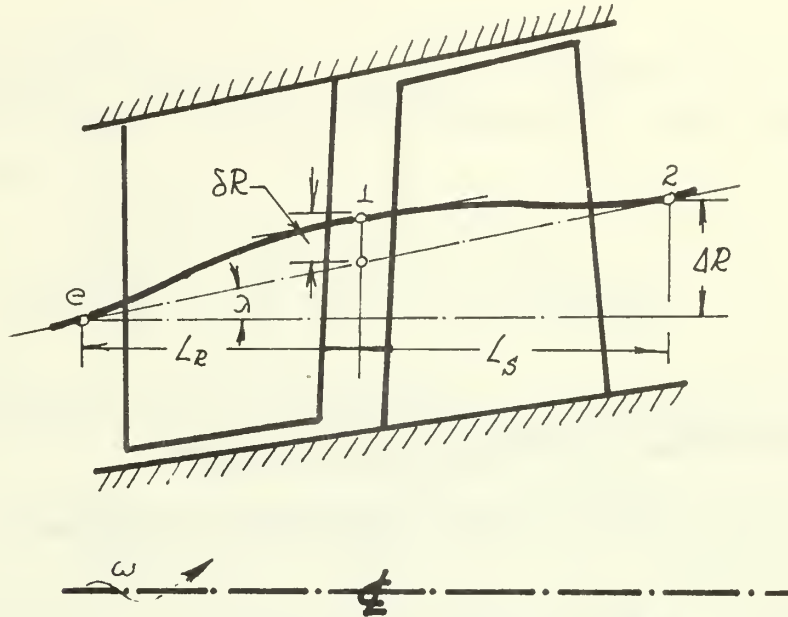


FIG. 2. GENERAL LAYOUT

2. General Equations Used (See Ref. 1)

$$\frac{dV_a^2}{dR} + F V_a^2 + G = 0 \quad (1)$$

where
$$F = - \frac{2}{V_a} \frac{\partial V_r}{\partial z} - \frac{1}{C_p} \frac{1}{\cos^2 \lambda} \frac{\partial S}{\partial R} \quad (2)$$

$$G = 2 \frac{V_u}{R} \frac{\partial (R V_u)}{\partial R} - 2 \frac{\partial H}{\partial R} + \frac{1}{C_p} (2H - V_u^2) \frac{\partial S}{\partial R} \quad (3)$$

with
$$- \frac{2}{V_a} \frac{\partial V_r}{\partial z} = \frac{2K_m}{\cos^3 \lambda} = \pm 2K \frac{\delta R}{L^2} \quad (4)$$

The minus sign holds for stations (e) and (2) and the plus sign for station (1)*

*Note that there is a discrepancy between the way equation (4) is interpreted here and in ref. 1. However, positive curvature is considered here in accordance with the way equations (1), (2) and (3) have been developed.

$$\text{where } \tan \lambda_e = \tan \lambda_1 = \tan \lambda_2 = \frac{\Delta R}{2L} \quad (5)$$

$$L = \frac{L_S + L_R}{2} \quad (\text{See Fig. 2}) \quad (6)$$

K takes the values 4 to 6.

The solution of equation (1) is given as follows

$$\begin{aligned} V_a^2 &= \exp \left(- \int_{R_h}^R F dR \right) \left[V_{ah}^2 - \int_{R_h}^R G \exp \left(+ \int_{R_h}^{R'} F dR' \right) dR \right] \\ &= V_{ah}^2 e^{-\int_{R_h}^R F dR} - e^{-\int_{R_h}^R F dR} \cdot \int_{R_h}^R G e^{\int_{R_h}^{R'} F dR'} dR \end{aligned} \quad (7)$$

3. Dimensional and Non-Dimensional Quantities

The basic quantities used are expressed as follows

Lengths in (ft)

velocities in (ft/s)

angular velocity ω in (rad/s)

enthalpies in (ft²/s²) or ($\frac{\text{ft-lb}}{\text{slug}}$)

entropies in ($\frac{\text{ft} - \text{lb}}{\text{slug}, ^\circ\text{R}}$) or ($\frac{\text{ft}^2}{\text{s}^2, ^\circ\text{R}}$)

the specific heat c_p in ($\frac{\text{ft} - \text{lb}}{\text{slug}, ^\circ\text{R}}$) or ($\frac{\text{ft}^2}{\text{s}^2, ^\circ\text{R}}$)

the density in (slug/ft³)

Consequently F has dimensions (ft⁻¹)

G has dimensions (ft/s²)

Calculations will be formed with non-dimensional quantities. As reference quantities will be used: The angular speed ω , the mean radius R_m , where

$$R_m = \frac{R_{t1} + R_{h1}}{2} \quad (7a)$$

the atmospheric pressure, temperature and density. We shall call all non-dimensional quantities starred quantities and denote them with a star.

- Lengths will be non-dimensional over R_m . Consequently

$$R^* = \frac{R}{R_m}$$

$$L^* = \frac{L}{R_m}$$

- Velocities will be non-dimensionalized over ωR_m . Consequently (where $V_{ref} = \omega R_m$)

$$V_a^* = \frac{V_a}{\omega R_m}, \quad W_u^* = \frac{W_u}{\omega R_m}, \quad U^* = \frac{U}{\omega R_m} = R^*$$

- Enthalpies will be non-dimensionalized over $\omega^2 R_m^2$

$$h^* = \frac{h}{\omega^2 R_m^2}; \quad H^* = \frac{H}{\omega^2 R_m^2}$$

- Entropies will be non-dimensionalized over C_p
- Densities will be non-dimensionalized over the atmospheric density
- Pressures will be non-dimensionalized over the atmospheric pressure

4. Problem Formulation

Using non-dimensional quantities (in the described way), we arrive at the following equations

$$\frac{d(V_a^*)^2}{dR^*} + F^*(V_a^*) + G^* = 0 \quad (1a)$$

where

$$F^* = -\frac{2}{V_a^*} \frac{\partial V_r^*}{\partial z^*} - \frac{1}{\cos^2 \lambda} \frac{\partial (S/C_p)}{\partial R^*} \quad (2a)$$

$$G^* = 2 \frac{V_u^*}{R^*} \frac{\partial(R^* V_u^*)}{\partial R} - \frac{2\partial H^*}{\partial R^*} + (2H^* - (V_u^*)^2) \frac{\partial(S/C_p)}{\partial R^*} \quad (3a)$$

and

$$\left. \begin{aligned} F^* &= F R_m \\ G^* &= G/\omega^2 R_m \end{aligned} \right\} \quad (8)$$

We shall consider now Figure 3. Considering stations (1), (2) and (3)

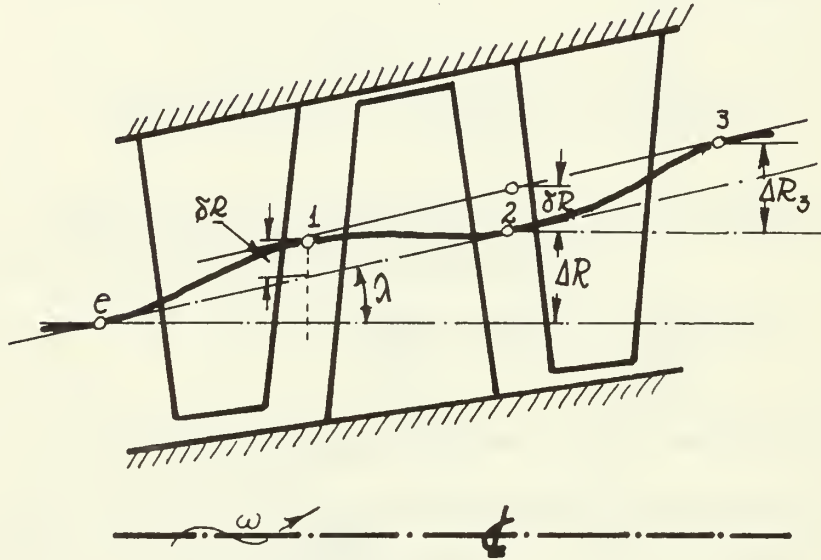


FIGURE 3.

we can see that the angle λ can be found from

$$\tan \lambda = \frac{\Delta R_3}{2L} = \frac{R_3 - R_1}{2L}$$

and still the curvature be calculated using δR at station (2) which is now negative measured from the straight line (1) - (3), instead from the straight line (e) - (2). The curvature expression remains the same if this sign change is taken into account.

5. Necessary Inlet Conditions

Quantities will be specified at equal radial distances at the inlet. The distribution of total enthalpy H and the distribution of entropy s must be specified at the inlet. This distribution of entropy and total enthalpy will be considered to have been developed through an adiabatic process (previously existing stages), starting from uniform atmospheric conditions. The atmospheric total pressure and temperature must be also given. Entropies will be measured considering as origin the atmospheric entropy.

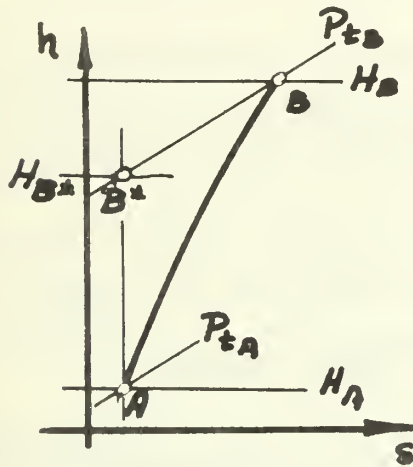


FIG. 4. ADIABATIC COMPRESSION
WITH FRICTION.

Considering an adiabatic compression from (A) (atmospheric conditions) to (B) (conditions at the stage inlet) along a stream surface, we have (see Fig. 4 for symbols)

$$S_B - S_{B^*} = C_p \ln \left(\frac{H_B}{H_{B^*}} \right) = S_B - S_A = \Delta S$$

or

$$H_{B^*} = H_B e^{-\Delta S/C_p}$$

from where H_{B^*} can be calculated. For an isentropic process we have also (from state A to state B*)

$$\frac{P_{tB^*}}{P_{tA}} = \frac{P_{tB}}{P_{tA}} = \left(\frac{H_{B^*}}{H_A} \right)^{\gamma/(\gamma-1)} = \left(\frac{H_B e^{-\Delta S/C_p}}{C_p T_{tA}} \right)^{\frac{\gamma}{(\gamma-1)}}$$

from where the total pressure at the compressor inlet can be calculated. The stagnation density ρ_t is given then as

$$\rho_t = \frac{P_t}{R_g T_t} = \frac{C_p P_t}{R_g H_t}$$

6. General Method of Solution

As can be seen an iterative process is necessary to solve the problem. A first approximation of the streamline position is assumed and on this basis the radial distribution of the axial velocity V_a^* is calculated at stations (1), (2) and (3), that satisfies the continuity equation on the whole.

Then, a new approximation of the streamline position is achieved by requiring that the same mass flow passes through individual stream-tubes at stations (2) and (3), the radial positions at station (1) remaining the same.

A new V_a^* -distribution is then calculated and the iteration continues until the specified number of iterations is achieved. The printed error of each iteration gives us an indication of the convergence of the procedure.

Having established the equations to be solved, a general flow diagram is given in Table I describing the general layout of the program.

7. Detailed Calculations (Following flow diagram of Table I).

Block (1)

At stations (1), (2) and (3)
equidistant radii are considered

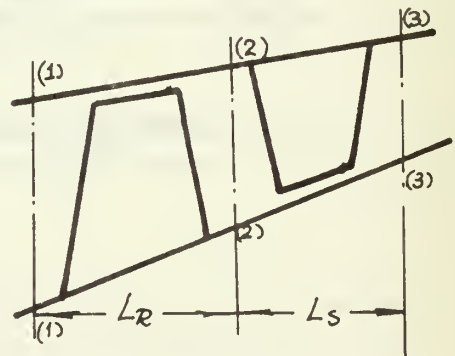


FIG. 5.

Block (2)

The total enthalpy increase inside the rotor is

$$\Delta H = \omega (R_2 V_{u2} - R_1 V_{u1})$$

$$\text{or } \Delta H^* = \frac{\Delta H}{\omega^2 R_m^2} = R_2^* V_{u2}^* - R_1^* V_{u1}^*$$

The reaction factor is

$$RF = \frac{V_{u1} + V_{u2}}{U_1 + U_2} = \frac{V_{u1}/\omega R_m + V_{u2}/\omega R_m}{U_1/\omega R_m + U_2/\omega R_m} = \frac{V_{u1}^* + V_{u2}^*}{R_1^* + R_2^*}$$

or finally

$$V_{u1}^* = \frac{RF(R_1^* + R_2^*) - \Delta H^*/R_2^*}{1 + R_1^*/R_2^*} \quad (9)$$

$$V_{u2}^* = \frac{RF(R_1^* + R_2^*) + \Delta H^*/R_1^*}{1 + R_2^*/R_1^*} \quad (10)$$

$$V_{u3}^* = V_{u1}^*$$

Block (3)

Calculations are performed without losses in the stage nor curvature effects for the first iteration. Corresponding terms are set here equal to zero.

Block (4)

The curvature term is calculated according to equation (4) rewritten here

$$\frac{CRTERM}{R_m} = - \frac{2}{V_a} \frac{\partial V_r}{\partial z} = \pm 2K \frac{\delta R}{L^2} \quad (11)$$

Note that in the way Vavra describes the curvature in page 453 of ref. (1), there exists an inconsistency in sign with the derived equations of motion. In fact the plus sign belongs to station $z = 0$ of ref. (1) or stations (1) and (3) here, while the minus sign to station (2) here (if δR is taken to be a positive quantity). The expression for the curvature term then becomes

$$\begin{aligned} CRTERM &= - \frac{2}{V_a} \frac{\partial V_r}{\partial z} R_m = \pm 2K \frac{\delta R}{L^2} R_m = \\ &= \pm 2K \frac{\delta R^*}{\left(\frac{L_S^* + L_R^*}{2}\right)^2} = \pm K \frac{\frac{R_3^* + R_1^*}{2} - R_2^*}{\left(\frac{L_S^* + L_R^*}{2}\right)^2} \end{aligned} \quad (12)$$

In this expression δR^* is positive in the way shown in fig. 3 and (+) sign applies to stations (1) and (3) while (-) applies to station (2).

The losses in total pressure are calculated in a subroutine, the theoretical basis of which is given in appendix B. This was decided in order to have the freedom of introducing any loss-correlation we desire.

The subroutine will furnish to us the decrease in total pressure non-dimensionalized over the atmospheric pressure.

The resulting entropy increase will then be calculated as

$$\frac{\Delta S}{C_p} = - \frac{R_g}{C_p} \ln \left(\frac{P_o - \Delta P_o}{P_o} \right)$$

where P_o corresponds to the total pressure level without losses. For the rotor this total pressure is P_{t1}' (see fig. 1) which is the corresponding total pressure that would result if the addition of enthalpy $H_2 - H_1$ were done isentropically. Then we have

$$\frac{P_{t1}'}{P_{t1}} = \left(\frac{H_2}{H_1} \right)^{\frac{\gamma}{\gamma-1}} \quad \text{or} \quad \frac{P_{t1}^*}{P_{t1}^*} = \left(\frac{H_2^*}{H_1^*} \right)^{\frac{\gamma}{\gamma-1}} \quad (13)$$

and

$$\begin{aligned} \frac{S_2 - S_1}{C_p} &= - \frac{R_g}{C_p} \ln \left[\frac{P_{t1}^* \left(\frac{H_2^*}{H_1^*} \right)^{\frac{\gamma}{\gamma-1}} - (\Delta P_o^*)_R}{P_{t1}^* \left(\frac{H_2^*}{H_1^*} \right)^{\frac{\gamma}{\gamma-1}}} \right] = \\ &= - \frac{R_g}{C_p} \ln \left[1 - \frac{\Delta P_{t1}^*}{P_{t1}^*} \left(\frac{H_1^*}{H_2^*} \right)^{\frac{\gamma}{\gamma-1}} \right] = S_2^* - S_1^* \quad (14) \end{aligned}$$

For the stator P_o comes to be equivalent to P_{t2} and the increase in entropy from station (2) to station (3) is given as

$$\frac{\Delta S}{C_p} = - \frac{R_g}{C_p} \ln \left(\frac{P_{t2} - (\Delta P_o)_S}{P_{t2}} \right)$$

or

$$\frac{S_3 - S_2}{C_p} = S_3^* - S_2^* = - \frac{R_g}{C_p} \ln \left(1 - \frac{(\Delta P_o^*)_S}{P_{t2}^*} \right) = S_3^* - S_2^* \quad (15)$$

Block (5)

The subroutine DERIR (see description in ref. (4)) is used to find the derivatives of a function given at discrete points. Thus $\frac{\partial H^*}{\partial R^*}$, $\frac{\partial S^*}{\partial R^*}$ and $\frac{\partial(R^*V_u^*)}{\partial R^*}$ are calculated. Then the functions F^* and G^* are calculated as given in equations (2a) and (3a).

Block (6)

The integrals of equation (7) are calculated (FUNC1 and FUNC2) and the distribution of $(V_a^*)^2$ is considered in the following form

$$(V_a^*)^2 = \text{FUNC1} \quad (V_{ah}^*)^2 + \text{FUNC2}$$

An iteration is initiated using as starting V_{ah}^* value one which does not make the quantity $(V_a^*)^2$ negative. The iteration scheme is described in ref. 4 (iteration subroutine ITERN).

For each value of (V_{ah}^*) , the (V_a^*) - distribution is calculated for the station under consideration. The iteration process ends when the continuity equation is satisfied.

Block (7)

The continuity equation is considered in the following way. Consider the actual axial velocity distribution at a section, $V_a^* = V_a^*(R^*)$. Then the corresponding mass flow is

$$Q_{\text{real}}^* = \int_{R_h}^{R_t} 2\pi\rho^*V_a^*R^*dR^* \quad (16)$$

Consider now a hypothetical situation where the part of the inviscid flow distribution of V_a^* is extended inside the wall boundary layer regions up to the walls. Then using this distribution we get a mass flow rate Q^* , where

$$Q^* = \int_{R_h}^{R_t} 2\pi\rho^*V_{a\text{inviscid}}^*R^*dR^*$$

then

$$Q^* > Q_{\text{real}}^*$$

and $V_{a\text{inviscid}}^*(R^*)$ differ from $V_a^*(R^*)$ only inside the wall boundary layer regions.

We can say now that normally a flow rate Q^* would pass through the area given, if it were not for the wall boundary layer presence. Defining a blockage factor K_b as

$$K_b = \frac{Q^*_{\text{real}}}{Q^*} \quad (17)$$

then

$$\frac{Q^*_{\text{real}}}{K_b} = Q^* = \int_{R_h}^{R_t} 2\pi \rho^* V_{a^*}^{\text{inviscid}} R^* dR^* \quad (18)$$

where the mass flow rate has been non-dimensionalized as follows

$$Q^* = \frac{Q}{\rho_{\text{atm}} \omega R_m^3}$$

In the program the inviscid velocity distribution $V_{a^*}^{\text{inviscid}}$ is calculated and throughout the whole report this is being referred to as V_a^* . The mass flow calculated at each station then is Q^* and then $K_b Q^*$ is compared with Q^*_{real} .

The calculation of the density ρ^* needed in the continuity equation is performed as follows: The absolute velocity is calculated as

$$\begin{aligned} V^* &= \sqrt{(V_u^*)^2 + (V_a^*)^2 + (V_r^*)^2} \\ &= \sqrt{(V_u^*)^2 + (V_a^*)^2 + (V_a^*)^2 \tan^2 \lambda} \end{aligned} \quad (19)$$

The static temperature is calculated as

$$T = \frac{H^*}{C_p} - \frac{(V^*)^2}{C_p} \quad \omega R_m^2 \quad (^{\circ}\text{R}) \quad (20)$$

The velocity of sound is calculated as

$$a^* = \frac{a}{\omega R_m} = \frac{\sqrt{\gamma R_g T}}{\omega R_m} \quad (21)$$

The Mach number is calculated as

$$M = \frac{V^*}{a^*} \quad (22)$$

Then the density is:

$$\begin{aligned}
 \rho^* &= \frac{\rho}{\rho_{atm}} = \frac{C_p}{R_g} \frac{P_t}{H} \frac{P_t}{\rho_{atm}} \left(1 + \frac{\gamma-1}{2} M^2 \right)^{-\frac{1}{(\gamma-1)}} \\
 &= \frac{C_p}{R_g} \frac{P_t^*}{H^*} \frac{P_{atm}}{\omega^2} \frac{P_{atm}}{R_m^2} \frac{1}{\rho_{atm}} \left(1 + \frac{\gamma-1}{2} M^2 \right)^{-\frac{1}{(\gamma-1)}} \\
 &= \frac{P_t^*}{H^*} H_{atm}^* \left(1 + \frac{\gamma-1}{2} M^2 \right)^{-\frac{1}{(\gamma-1)}} \quad (23)
 \end{aligned}$$

The calculation of the mass flow rate at each radial position is performed with the subroutine SUMAT which uses Simpson's rule for unequal intervals. The subroutine SUMAT makes use of the subroutine INTP~~o~~ for interpolation which is described in detail in ref. 2.

Once these calculations are performed the program gives control to the subroutine ITERN which performs the iteration, until convergence has been realized and the continuity equation is satisfied.

Block (8)

The radial position of the streamlines at station (1) is considered the same throughout the calculation and in this step the radial positions of the streamlines at stations (2) and (3) are found with the condition that the same mass flow is allowed to pass through each streamtube with the newly calculated axial velocity distribution.

Block (9)

The square root of the sum of the squares of the difference between the old and new position of the streamlines is calculated for stations (2) and (3). This is considered here as an indication of the convergence of the procedure. Additionally in this step all pertinent quantities that have not been calculated up to now are calculated (static and total pressures, relative velocities and mach numbers, angles, etc).

Block 10

Once the prescribed number of iterations has been performed, some additional pertinent dimensional and non-dimensional quantities are calculated (a description of the calculation is given in Appendix C), and all the results are printed.

The whole procedure is executed as many times as additional set of data exist.

8. Description of the Use of the Program

This program has been constructed as a complement to ref. 2. An effort was made to take into account entropy and energy gradients (entropy gradients existing at the inlet or introduced through the loss correlations after each row, and energy gradients existing at the inlet or introduced by a non-uniform work distribution in the rotor) and compressibility effects.

The non-dimensionalization proposed in ref. 2 which does not take these effects into account is rendered thus incomplete and it was decided to carry out the calculation in the non-dimensional form proposed in reference 2 and modified slightly as described already, introducing, however, the data in dimensional form, reflecting thus the Mach number level.

A detailed description of the program has already been given. The meaning of the weight factor has to be explained here. It happens sometimes in complicated cases that the iteration procedure diverges when the calculated corrections for the new streamline position are used in the whole. If, however, a fraction of the corrections is considered and introduced for the next iteration, the iteration procedure may be forced to converge. The weight factor ($0. < W.F. \leq 1.$) introduced as data to the program defines the fraction of the correction to be used for the following iteration loop.

Cases have been already run for no curvature effects and no losses. Then losses were introduced and curvature effects. It was found that to take into account the curvature effects and have an converging iteration process, a value of the weight factors smaller than unity ought to be used.

To facilitate the use of the program a table with a typical input has been prepared and given in Table II. The maximum number of streamlines is taken to be eleven. The listing of the program along with the subroutines in use is given in Table III. The results of the already given typical input are given in Table IV. The explanation of the symbols used along with all the pertinent parameters used in the program are given in the FORTRAN Symbol Table. The output symbols not described in the FORTRAN Symbol Table will be found in the Output Symbol Table. For dimensional quantities the already given dimensions are used. For non-dimensional quantities the already described non-dimensionalization has been done. In the FORTRAN Symbol Table the dimensional variables are given. The non-dimensional ones are denoted in the program with the letter S at the end of the name of the dimensional quantity unless otherwise stated.

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2. Vavra, M. H., Aerodynamic Design of Symmetrical Blading for Three-Stage Axial Flow Compressor Test Rig, NPS-57Va70091A, Naval Postgraduate School, Sept. 1970.
3. Sleinke, Ronald and Crouse, James, Analytical Studies of Aspect Ratio and Curvature Variations for Axial-Flow-Compressor-Inlet Stages under High Loading.
4. Papailiou, K. D., Roels, N., and Schwes, F., Some IBM 1130 Auxiliary Subroutines, Von Karman Institute IN 31 (1969).

TABLE OF FORTRAN SYMBOLS USED IN THE MAIN PROGRAM

Remarks:

- (a) If a variable is dimensioned by (11, 3) this means that the variable allows for maximum eleven radial stations and for the three axial positions.
- (b) If a variable is dimensioned by (11) this means that the variable allows for maximum eleven radial positions.
- (c) Unless otherwise indicated in the symbol table all non-dimensional or starred quantities are indicated by adding an S to the name of the dimensional variable.

FORTTRAN SYMBOL	SYMBOL	UNITS	DESCRIPTION
VREF	V_{ref}	ft/s	reference velocity, equals ωR_m
NITER	--	--	The number of iterations desired before printing the results
CURV	k	--	The constant (usually taking the value 4) appearing in the curvature term
KB(3)	k_B	--	blockage factor array for the three stations
ROT(11,3)	ρ_t	slug/ft ³	total density table
MSFLOW	Q	slug/sec	mass flow rate
MSFLOS	Q^*	--	non-dimensional mass flow rate
DUM(11),		--	Auxiliary variables
RR(11),		--	
RRR(11)		--	
DVUDR(11,3)	$\frac{\partial(R^*V_u^*)}{\partial R^*}$	--	tangential velocity gradient table
LAMDA(11)	λ	rad	angle defined in figure (2)
CRTERM(11)		--	curvature term table
DPTS(11)	ΔP_t^*	--	non-dimensional total pressure loss table for all radial positions at the station considered
DSDRS(11,3)	$\frac{\partial S^*}{\partial R^*}$	--	entropy gradient table
DHDRS(11,3)	$\frac{\partial H^*}{\partial R^*}$	--	total enthalpy gradient

FORTTRAN SYMBOL	SYMBOL	UNITS	DESCRIPTION
OMEGA	ω	sec ⁻¹	angular velocity of the rotor
PI	π	--	3.141593
RPM	rpm	min ⁻¹	revolutions per minute
RM	R_m	ft	mean diameter at station (1)
RH1 RH2 RH3	$\left. \begin{matrix} R_{h1} \\ R_{h2} \\ R_{h3} \end{matrix} \right\}$	ft	hub diameters at stations (1), (2), and (3) respectively
RT1 RT2 RT3	$\left. \begin{matrix} R_{t1} \\ R_{t2} \\ R_{t3} \end{matrix} \right\}$	ft	tip diameters at stations (1), (2), and (3) respectively
N	VREF	Vref	reference velocity (ωR_m)
	n	--	number of radial equidistant positions considered
GAMA	γ	--	isentropic exponent of gas
RG	R_g	$\frac{\text{ft} - \text{lb}}{\text{slug, OR}}$	gas constant
CP	C_p	$\frac{\text{ft} - \text{lb}}{\text{slug, OR}}$	gas specific heat
ROATH	ρ_{atm}	slug/ft ³	atmospheric density
PATM	P_{atm}	lb/ft ²	atmospheric pressure
TATM	T_{atm}	OR	atmospheric temperature
HATM	H_{atm}	$\frac{\text{ft}^2}{\text{sec}^2}$	atmospheric total enthalpy

FORTRAN SYMBOL	SYMBOL	UNITS	DESCRIPTION
PT(11,3)	P_t	lb/ft ²	total pressure table for all radial positions at the three stations
H(11,3)	H	$\frac{\text{ft}^2}{\text{sec}^2}$	total enthalpy table for all radial positions at the three stations
S(11,3)	S	$\frac{\text{ft} - \text{lb}}{\text{slug} \cdot \text{OR}}$	entropy table (measured from atmospheric conditions) for all radial positions at three stations
DH(11)	ΔH	$\frac{\text{ft}^2}{\text{sec}^2}$	increase in total enthalpy at all radial positions inside the rotor
TEST1	--	--	indicator. It indicates the number of passes
R(11,3)	R^*, R	-- or ft	the non-dimensionalized radii table for all radial positions at all radial stations
LR	L_R, L_R^*	ft or --	axial length of the rotor used with dimensions first and without dimensions later
LS	L_S, L_S^*	ft or --	axial length of the stator used with dimensions first and without dimensions later
VA(11,3)	V_a	ft/sec	axial velocity table
VR(11,3)	V_r	ft/sec	radial velocity table
VU(11,3)	V_u	ft/sec	peripheral velocity table
RF(11)	R.F.	--	reaction factor table for all radial positions
SIGR(11)	σ_R	--	rotor solidity array for all radial positions
SIGS(11)	σ_S	--	stator solidity array for all radial positions
WFACT	--	--	weight factor

FORTRAN SYMBOL	SYMBOL	UNITS	DESCRIPTION
DUM1(11)	--	--	Auxiliary or dummy variables
DUM2(11)	--	--	
DUM3(11)	--	--	
DUM4(11)	--	--	
DER(11)	--	--	
DEB,FIN,	--	--	Variables employed in subroutine ITERN See ref. 3 for explanations
DE,NAL,	--	--	
EPS,F2,NS	--	--	
V(11,3)	V	ft/s	absolute velocity table.
MSFLS(11,3)		--	mass flow rate table passing from each streamtube at each station
SOND(11,3)	a	ft/s	velocity of sound table
TOT(11,3)	T _t	OR	total temperature table
U(11,3)	U	ft/s	peripheral velocity table
C(11,3)	W	ft/s	relative velocity table
WU	W _u	ft/s	peripheral component of relative velocity table
F(11,3)	F*	--	function appearing in the radial equilibrium equation
G(11,3)	G*	--	function appearing in the radial equilibrium equation
FUNC1(11), FUNC2(11)		-- --	function appearing in the solution of the radial equilibrium equation
SOUND(11,3)	a*	a*	non-dimensional velocity of sound
T(11,3)	T _s	OR	static temperature table
MACH(11,3)	M	--	Mach number table

FORTAN SYMBOL	SYMBOL	UNITS	DESCRIPTION
STDEN(11,3)	ρ^*	--	non-dimensional static density table
ERROR(3)		--	the mean square root of the differences of the old and new streamline positions indicating the convergence status
DPTR(11)	$(\Delta P_t^*)_R$	--	non-dimensional total pressure increase through rotor table
DPTST(11)	$(\Delta P_t^*)_{ST}$	--	non-dimensional total pressure increase through stage table
DPSR(11)	ΔP_R^*	--	non-dimensional static pressure increase through rotor table
DPSS(11)	ΔP_S^*	--	non-dimensional static pressure increase through stator table
DPSST(11)	ΔP_{ST}^*	--	non-dimensional static pressure increase through stage table
TT2IS	$(T_{t2})_{is}$	OR	isentropic total temperature at station (2)
TS3IS	$(T_3)_{is}$	OR	isentropic static temperature at station (3)
TT3IS	$(T_{t3})_{is}$	OR	isentropic total temperature at station (3)
WS(11,3)	W^*	--	non-dimensional relative velocity table
MACHR(11,3)	M_R	--	relative Mach number table
P(11,3)	P	lb/ft ²	static pressure table
RO(11,3)	ρ	slug/ft ³	static density table

FORTRAN SYMBOL	SYMBOL	UNITS	DESCRIPTION
ETAR(11)	η_R	--	total to total rotor efficiency table
ETAS(11)	η_S	--	static to static stator efficiency table
HSTTT	$(\eta_{ST})_{T-T}$	--	total to total stage efficiency
HSTSS	$(\eta_{ST})_{S-S}$	--	static to static stage efficiency
PTBAR1	\bar{P}_{t1}^*	--	non-dimensional mass averaged total pressure at rotor inlet
PSBAR1	\bar{P}_1^*	--	non-dimensional mass averaged static pressure at rotor inlet
ETRBAR	$\bar{\eta}_R$	--	mass averaged total to total rotor efficiency
DPTRB	$(\bar{\Delta P}_t^*)_R$	--	non-dimensional mass averaged total pressure increase through the rotor
HSTTTB	$(\bar{\eta}_{ST})_{T-T}$	--	mass-averaged total to total stage efficiency
HSTTSB	$(\bar{\eta}_{ST})_{T-S}$	--	mass-averaged total to static stage efficiency
PTBAR2	\bar{P}_{t2}^*	--	non-dimensional mass-averaged total pressure at rotor exit
PTBAR2	\bar{P}_2^*	--	non-dimensional mass-averaged static pressure at rotor exit
ETSBAR	$\bar{\eta}_S$	--	mass-averaged static to static stator efficiency
PTBAR3	\bar{P}_{t3}^*	--	non-dimensional mass-averaged total pressure at the stator exit
PSBAR3	\bar{P}_3^*	--	non-dimensional mass-averaged static pressure at the stator exit
WFACT		--	weight factor

Output Symbol table

DF	Diffusion factor
----	------------------

ETA T-T	η_{T-F}
---------	--------------

ETA S-S	η_{S-S}
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THE REACTION FACTOR WITH AXIAL VELOCITY VARIATIONS

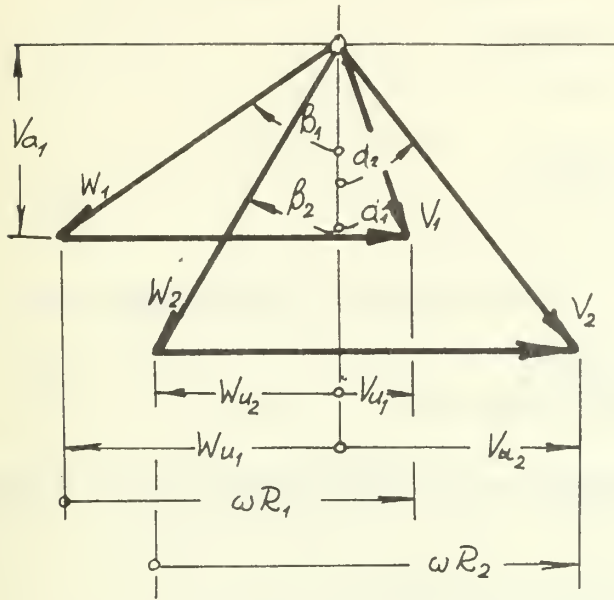


FIG. 1(A) VELOCITY TRIANGLES

FIGURE 1A

$$R_1 \neq R_2$$

$$\Delta H = \omega(R_2 V_{u2} - R_1 V_{u1})$$

$$r^* = \frac{\Delta P_R}{\Delta P_{ST}}$$

Assuming no losses, for incompressible flow

$$\Delta P_R = P_2 - P_1 = (P_{t2})_{REL} - (P_{t1})_{REL} + \rho \left(\frac{U_2^2 - U_1^2}{2} + \frac{W_1^2 - W_2^2}{2} \right)$$

$$= \frac{1}{2} \rho (W_1^2 - W_2^2) + \frac{1}{2} \rho (U_2^2 - U_1^2)$$

$$= \frac{1}{2} \rho (W_{u1}^2 - W_{u2}^2 + V_{a1}^2 - V_{a2}^2)$$

$$+ \frac{1}{2} \rho (U_2^2 - U_1^2)$$

$$\Delta P_{ST} = \omega(R_2 V_{u2} - R_1 V_{u1}) \rho$$

which turns out to give a rather complicated formula for the reaction factor. Consequently, we shall assume that the quantity

$$\frac{V_{u1} + V_{u2}}{U_1 + U_2}$$

is specified along corresponding radii.

APPENDIX B

The correlation described in reference 3 will be used for the calculation of losses (see also reference 4)

The loss coefficient ζ_P is defined for rotors as

$$\zeta_{PR} = \frac{(\Delta P_O)_R}{P_{t1} - P_1} = \frac{(\Delta P_O^*)_R}{P_{t1}^* - P_1^*} \quad (B1)$$

where $\Delta \bar{P}_t$ is the mass averaged total pressure loss, and for stators as

$$\zeta_{PS} = \frac{(\Delta P_O)_S}{P_{t2} - P_2} = \frac{(\Delta P_O^*)_S}{P_{t2}^* - P_2^*} \quad (B2)$$

This definition holds for incompressible flow where the density is assumed constant

The diffusion factor D is given for rotors as

$$D_R = 1 - \frac{W_2}{W_1} + \frac{R_1 W_{u1} - R_2 W_{u2}}{\sigma_R (R_1 + R_2) W_1} \quad (B3)$$

and for stators as

$$D_S = 1 - \frac{V_3}{V_2} + \frac{R_2 V_{u2} - R_3 V_{u3}}{\sigma_S (R_2 + R_3) V_2} \quad (B4)$$

$$\text{or} \quad D_R = 1 - \frac{W_2^*}{W_1^*} + \frac{R_1^* W_{u1}^* - R_2^* W_{u2}^*}{\sigma_R (R_1^* + R_2^*) W_1^*} \quad (B3a)$$

$$D_S = 1 - \frac{V_3^*}{V_2^*} + \frac{R_2^* V_{u2}^* - R_3^* V_{u3}^*}{\sigma_S (R_2^* + R_3^*) V_2^*} \quad (B3b)$$

then

$$\zeta_{PR} = \frac{2\sigma_R}{\cos \beta_2} \left[0.004 + 0.0639 (D_R + 0.1)^{2.91} + 0.228 D_R^{2.02} [1 - \lambda_R]^{3.77} \right] \quad (B5)$$

$$\text{where} \quad \lambda_R = \frac{R_{2t} - R_2}{R_{2t} - R_{2h}} = \frac{R_{2t}^* - R_2^*}{R_{2t}^* - R_{2h}^*} \quad (B6)$$

For angles $\beta_2 \geq 45^\circ$, see Fig. 1A, a correction is offered, where instead of ζ_{PR} the loss coefficient $(\zeta_{PR})_{COR}$ is considered, where

$$(\zeta_{PR})_{COR} = \zeta_{PR} \cos \beta_2 \sqrt{2} \left[1 - \frac{\pi}{4} + \frac{\pi \beta_2}{180} \right] \quad (B7)$$

For stators

$$\zeta_{PS} = \frac{2\sigma_S}{\cos \alpha_3} \left[0.004 + 0.0639 (D_S + 0.1)^{2.91} + 0.057 D_S^{2.02} [1 - \lambda_S]^{3.77} \right] \quad (B8)$$

where no correction is offered for $\alpha_3 > 45^\circ$.

The shock losses are calculated as follows:

The amount of supersonic turning is

$$\Delta v = \frac{0.625}{\sigma_R} (\beta_1 - \beta_2) \quad \text{for the rotor} \quad (B9)$$

$$= \frac{0.625}{\sigma_S} (\alpha_2 - \alpha_3) \quad \text{for the stator} \quad (B10)$$

The peak suction surface Mach number is then obtained from

$$(M_{Su}) = 1.095 + 0.03395 \Delta v + 1.086 (M_{R1} - 1.00)^{1.372} \quad (B11)$$

for a rotor

$$(M_{Su}) = 1.095 + 0.03395 \Delta v + 1.086 (M_2 - 1.00)^{1.372} \quad (B12)$$

for a stator

The shock losses are then calculated on the basis of the mean Mach number

$$M = \frac{M_{R1} + M_{Su}}{2} \quad \text{for a rotor} \quad (B13)$$

$$M = \frac{M_2 + M_{Su}}{2} \quad \text{for a stator} \quad (B14)$$

as

$$\zeta_{SH} = \frac{1 - \left[\frac{(\gamma+1)M^2}{(\gamma-1)M^2+2} \right]^{\gamma/(\gamma-1)} \left[\frac{\gamma+1}{2\gamma M^2 - (\gamma-1)} \right]^{1/(\gamma-1)}}{1 - \left[1 + \frac{\gamma-1}{2} M^2 \right]^{\gamma/(\gamma-1)}} \quad (B15)$$

where the final loss coefficient is obtained as

$$\zeta = \zeta_P + \zeta_{SH}$$

If the inlet Mach number is smaller than unity, the Mach number M_{Su} is calculated by taking the inlet Mach number M_{R1} or M_2 to be unity. The mean Mach number M then is calculated using the actual inlet Mach number M_{R1} or M_2 . If $M < 1$ no shock losses are assumed to exist. If $M > 1$, then the shock losses are calculated using equation (B15) and $M = 1$. As pointed out earlier, this procedure is adopted only if the inlet Mach numbers are smaller than unity.

APPENDIX C

The following additional calculations are performed in the program.

(a) The total pressure increase is

$$\Delta P_{t_R}^* = P_{t_2}^* - P_{t_1}^* \quad \text{for the rotor} \quad (C1)$$

$$\Delta P_{t_{ST}}^* = P_{t_3}^* - P_{t_1}^* \quad \text{for the stage} \quad (C2)$$

(b) The static pressure increase is

$$\Delta P_R^* = P_2^* - P_1^* \quad \text{for the rotor} \quad (C3)$$

$$\Delta P_S^* = P_3^* - P_2^* \quad \text{for the stator} \quad (C4)$$

$$\Delta P_{ST}^* = P_3^* - P_1^* \quad \text{for the stage} \quad (C5)$$

(c) The efficiency is calculated as follows

$$\eta_R = \frac{C_p(T_{t_{2is}} - T_{t_1})}{\Delta H} \quad \begin{array}{l} \text{total to total efficiency for the} \\ \text{rotor} \end{array} \quad (C6)$$

$$\eta_S = \frac{T_{3is} - T_2}{T_3 - T_2} \quad \begin{array}{l} \text{static to static efficiency for the} \\ \text{stator} \end{array} \quad (C7)$$

$$(\eta_{ST})_{T-T} = \frac{C_p(T_{t_{3is}} - T_{t_1})}{\Delta H} \quad \begin{array}{l} \text{total to total efficiency for} \\ \text{the stage} \end{array} \quad (C8)$$

$$(\eta_{ST})_{S-S} = \frac{(T_{3is} - T_1)}{T_3 - T_1} \quad \begin{array}{l} \text{static to static efficiency for} \\ \text{the stage} \end{array} \quad (C9)$$

The calculation of the temperatures is being done as follows

$$T_{t_{2is}} = T_{t_2} e^{-(S_2^* - S_1^*)/C_p} = T_{t_2} e^{-(S_2^* - S_1^*)} \quad (C10)$$

$$T_{3_{is}} = T_3 e^{-(s_3 - s_2)/C_p} = T_3 e^{-(s_3^* - s_2^*)} \quad (C11)$$

$$T_{t_{3_{is}}} = T_{t_3} e^{-(s_3 - s_1)/C_p} = T_{t_3} e^{-(s_3^* - s_1^*)} \quad (C12)$$

(d) Mass averaged quantities are calculated. Assuming that we want to calculate the mass averaged value of the quantity Y, then

$$\bar{Y} = \frac{\int_{R_{hub}}^{R_{tip}} 2\pi R V_a Y dR}{Q} = \frac{\int_{R_{hub}^*}^{R_{tip}^*} 2\pi \rho^* R^* V_a^* Y dR^*}{Q_{real}^*/K_b} \quad (C13)$$

or

$$\bar{Y}^* = \frac{2\pi K_b}{Q_{real}^*} \int_{R_{hub}^*}^{R_{tip}^*} \rho^* R^* V_a^* Y^* dR^* \quad (C13a)$$

SYMBOLS

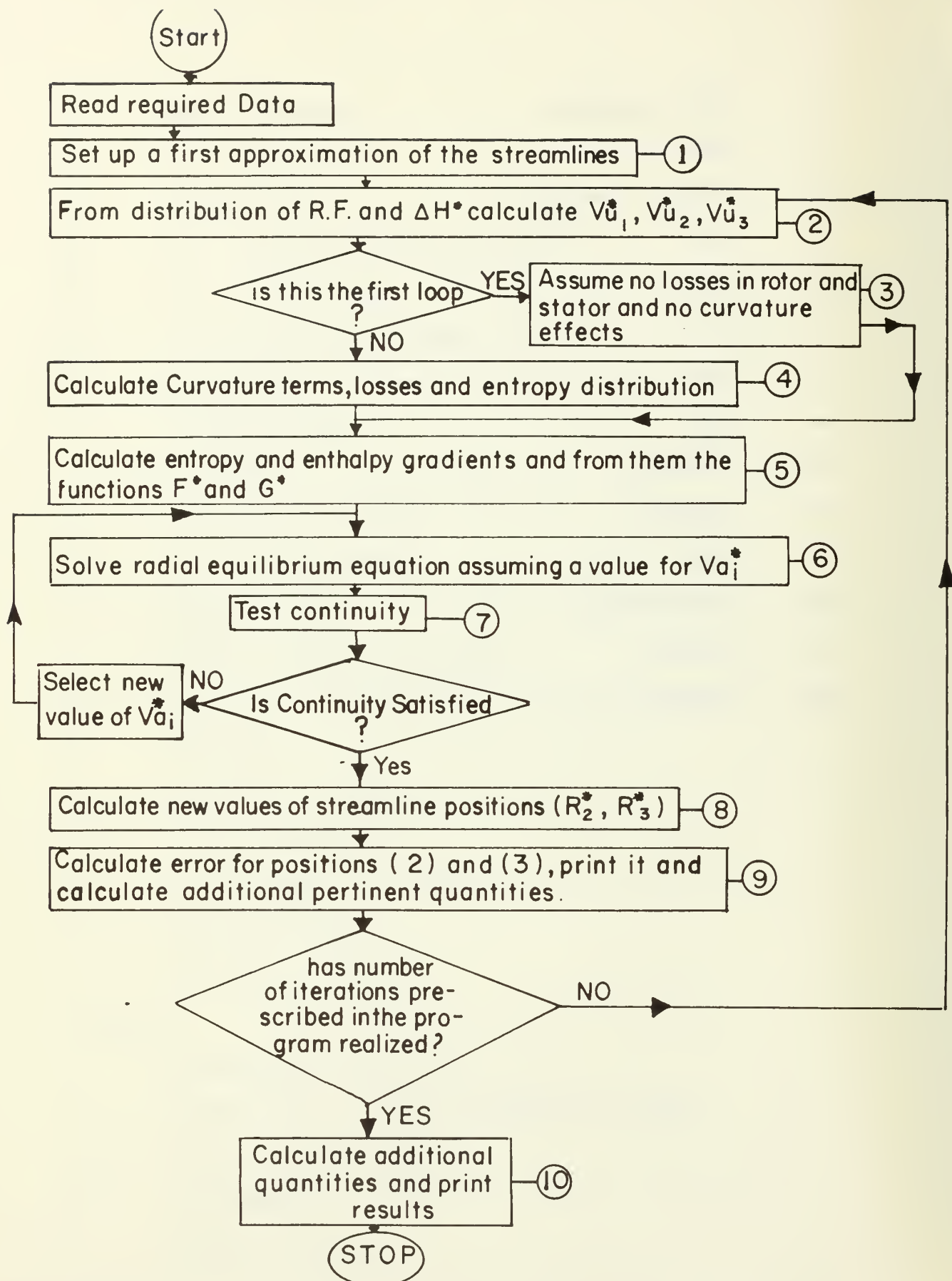
V	absolute velocity
W	relative velocity
U	peripheral velocity
H	total enthalpy
h	static enthalpy
P_t	total pressure
P	static pressure
S	entropy
R	radial distance from compressor axis
ω	angular velocity
L	axial length (see Fig. 2)
λ	angle between axial direction and streamline direction at stations (1), (2), and (3).
$\delta R, \Delta R$	radial distances defined in Fig 2.
F, G	functions defined in equations (1), (2), and (3)
C_p	specific heat at constant pressure
z	axial distance
K	constant used for the evaluation of curvature effects (see equation (4)).
ρ	static density
ρ_t	stagnation density
α	absolute angle measured from the axial direction
β	relative angle measured from the axial direction
R_g	gas constant
γ	ratio of the specific heats at constant pressure and constant volume

T	static temperature
T_t	total temperature
RF	reaction factor
ΔH	total enthalpy increase in the rotor
ΔP_o	loss in total pressure
K_b	wall boundary layer blockage factor
Q	mass flow rate
a	velocity of sound
M	Mach number
ΔP	static pressure increase
ΔP_t	total pressure increase
D	diffusion factor
σ	solidity (chord to pitch ratio)
λ_R, λ_S	non-dimensional quantities defined in equation B6
η	efficiency
ζ_P	profile loss coefficient
ζ_{sh}	shock loss coefficient
Δv	amount of supersonic turning
M	average mach number
ζ	total loss coefficient

Subscripts

1	station ahead of the rotor
2	station behind the rotor and ahead of the stator
3	station behind the stator
a	axial direction
u	peripheral direction

r	radial direction
is	isentropic
e	entrance (see Fig. 2)
R	rotor
s	stator
h	hub
t	tip
m	mean
atm	atmospheric
ref	reference
st	stage
su	suction surface
cor	corrected
rel	relative



NOTE: This procedure is repeated as many times as necessary to cover all cases introduced as data along with the program

GENERAL FLOW DIAGRAM OF THE PROGRAM

TABLE II

NCASE					
01					
N	NITER				
009020					
RH1	RH2	RH3	RT1		
+0.90000000E-00	+0.90000000E-00	+0.90000000E-00	+0.15000000E+01		
RT2	RT3	LS	LR		
+0.15000000E+01	+0.15000000E+01	+0.20800000E-00	+0.20800000E-00		
RF1	RF2	RF3	RF4		
+0.50000000E-00	+0.50000000E-00	+0.50000000E-00	+0.50000000E-00		
RF5	RF6	RF7	RF8		
+0.50000000E-00	+0.50000000E-00	+0.50000000E-00	+0.50000000E-00		
RF9					
+0.50000000E-00					
DH1	DH2	DH3	DH4		
+0.30295760E+05	+0.30295760E+05	+0.30295760E+05	+0.30295760E+05		
DH5	DH6	DH7	DH8		
+0.30295760E+05	+0.30295760E+05	+0.30295760E+05	+0.30295760E+05		
DH9					
+0.30295760E+05					

TABLE II (CONTINUED)

S1	S2	S3	S4
+0.	+0.	+0.	+0.
S5	S6	S7	S8
+0.	+0.	+0.	+0.
S9			
+0.			
CP	RPM	PATM	TATM
+0.60047000E+04	+0.22900000E+04	+0.21152300E+04	+0.52000000E+03
RG	CURV		
+0.17156300E+04	+0.40000000E+01		
H1	H2	H3	H4
+0.31224440E+07	+0.31224440E+07	+0.31224440E+07	+0.31224440E+07
H5	H6	H7	H8
+0.31224440E+07	+0.31224440E+07	+0.31224440E+07	+0.31224440E+07
H9			
+0.31224440E+07			
KB1	KB2	KB3	MSFLOW
+0.10000000E+01	+0.96500000E-00	+0.94000000E-00	+0.24516140E+01
SIGR1	SIGR2	SIGR3	SIGR4
+0.10610000E+01	+0.10200000E+01	+0.98500000E-00	+0.95500000E-00

TABLE II (CONTINUED)

SIGR5	SIGR6	SIGR7	SIGR8
+0.9280000E-00	+0.9050000E-00	+0.8840000E-00	+0.8650000E-00
SIGR9			
+0.8490000E-00			
SIGS1	SIGS2	SIGS3	SIGS4
+0.1226000E+01	+0.1110000E+01	+0.1010000E+01	+0.9240000E-00
SIGS5	SIGS6	SIGS7	SIGS8
+0.8490000E-00	+0.7820000E-00	+0.7230000E-00	+0.6700000E-00
SIGS9			
+0.6220000E-00			
WFACT			
+0.1000000E-00			

```

0001 REAL KB(3),LR,LS,MSFLOW,MSFLOS,MSFSL(11,3),LAMDA(11),MACH(11,3)
0002 1,MACHR(11,3)
0003 DIMENSION TEST1
1SS(11,3),HS(11,3),DSDRS(11,3),DHDRS(11,3),DUM1(11,3),DUM
2(11,3),RR(11,3),DER(11,3),F(11,3),G(11,3),FUNCI(11,3),FUNC2(11,3),VAS(11,3)
3RTERM(11,3),VRS(11,3),V(11,3),T(11,3),SOUND(11,3),DUM2(11,3),STDEN(11,3)
4),RRR(11,3),Z(3),W(3),ERROR(2),DUM3(11,3),DUM4(11,3),SIGS(11,3)
5,DIMENSION SIGR(11,3),VU(11,3),VA(11,3),VR(11,3),V(11,3),SOND(11,3)
1,TOT(11,3),WU(11,3),C(11,3),WUS(11,3),ALFA(11,3),BETA(11,3),WS(11,3)
2,DIMENSION DDIR(11,3),DPTS(11,3),DPSR(11,3),DPSST(11,3),ETAR(11,3)
1,ETAS(11,3),HSTT(11,3),HSTS(11,3),PTS(11,3),PS(11,3),DPTS(11,2)
COMMON R(11,3),DFAC(11,2),PTS(11,3),PS(11,3),DPTS(11,2)

0004
0005
0006
0007 DATA READOUT
0008 C***
0009 C***
0010 C***
0011 1100
0012 READ(5,1100) NCASE
0013 FORMAT(12)
0014 DO 950 NNUM=1, NCASE
0015 READ(5,100) RH1,RH2,RH3,RT1,RT2,RT3,LS,LR
0016 READ(5,100) (RH(I),I=1,N)
0017 READ(5,100) (DH(I),I=1,N)
0018 READ(5,100) (S(I),I=1,N)
0019 READ(5,100) (CP,RPM, PATM,TATM,RG,CURV
0020 READ(5,100) (KB(I),I=1,N)
0021 READ(5,100) (W(1),I=1,N)
0022 READ(5,100) (SIGR(I),I=1,N)
0023 READ(5,100) (SIGS(I),I=1,N)
0024 READ(5,100) WFACT
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SOME PRELIMINARY CALCULATIONS OF QUANTITIES USED THROUGHOUT

THE PROGRAM

PI=3.141593

OMEGA=PI*RGPM/30.

RM=(RH1+RT1)/2.

VREF=OMEGA*RM

AN=N-1

GAMA=1/(1.-RG/CP)

RCATM=RCATM/(RG*TATM)

HATM=CP*TATM

DO 200 I=1,N

PT(I,1)=PATM*(H(I,1)/EXP(S(I,1)/CP)/HATM)**(GAMA/(GAMA-1.))

DO 212 I=1,N

H(I,2)=H(I,1)+DH(I)

MSFLOS=MSFLOW/(ROATM*OMEGA*RM**3)

HATMS=HATM/VREF**2

NON DIMENSIONALIZED QUANTITIES

R(1,1)=RH1/RM

R(N,1)=RT1/RM

R(1,2)=RH2/RM

R(N,2)=RT2/RM

R(1,3)=RH3/RM

R(N,3)=RT3/RM

DO 201 I=1,N

SS(I,1)=S(I,1)/CP

HS(I,1)=H(I,1)/VREF**2

DHS(I,1)=DH(I,1)/VREF**2

PTS(I,1)=PT(I,1)/PATM

RCTS(I,1)=ROT(I,1)/ROATM

LS=LS/RM

DO 213 I=1,N

HS(I,2)=HS(I,1)+DHS(I)


```

00055 HS(I,3)=HS(I,2)
00056 C*** FIRST APPROXIMATION OF THE STREAMLINE POSITION (STEP 1)
00057 C***
00058 DC 203 I=1,3
00059 DR(I)=(R(N,I)-R(I,1))/ANI
00060 DO 202 J=1,3
00061 DO 202 I=2,N1
00062 R(I,J)=R(I-1,J)+DR(J)
00063 C***
00064 C*** PRINTOUT OF INPUT DATA
00065 C***
00066 WRITE(6,121)
00067 121 FCRRM(1H1,1X,INITIAL DATA',1X,'-----',7X,'RH1',14X,'RH2
00068 1,12X,'RH3',12X,'RI1',13X,'RT2',13X,'RT3')
00069 WRITE(6,122)1H1,RH2,RH3,RI1,RT2,RT3
00070 122 FORMAT(6(1X,E15.8),/)
00071 WRITE(6,123)LS,LR,RPM,RG,CURV,GAMA
00072 123 FORMAT(7X,E15.8),15X,'LR',14X,'RPM',12X,'RG',13X,'CURV',13X,'GAMA',
00073 1/,6(1X,E15.8)/)
00074 WRITE(6,124)KB(1),KB(2),KB(3),PATM,TATM,ROATM,MSFLOW
00075 124 FORMAT(7X,E15.8),14X,'KB2',12X,'KB3',13X,'PATM',13X,'TATM',11X,'RO
00076 2,15X,'DH',15X,'HI',13X,'PATM',13X,'MSFLOW',1X,E15.8,/,7X,'SL',15X,'RF
00077 125 WRITE(6,125)1S(1,1),RF(I),DH(I),HI(1),I=1,N)
00078 125 FORMAT(4(1X,E15.8))
00079 90J WRITE(6,1H1)
00080 90J WRITE(6,1H1)
00081 126,16X,FINAL RESULTS',1X,'-----',7X,'ITERATION',1,
00082 16X,ERROR 1,8X,ERROR 2,/)
00083 TEST1=1
00084 DC 280 IPASS=1,NITER
00085 C*** CALCULATION OF VU1*, VU2*, VU3* ( STEP 2 )
00086 C***
00087 DC 204 I=1,N
00088 VUS(I,1)=(RF(I)*(R(I,1)+P(I,2))-DHS(I)/R(I,2))/(1+R(I,1)/R(I,2))
00089 VUS(I,2)=(RF(I)*(R(I,1)+R(I,2))+DHS(I)/R(I,1))/(1+R(I,2)/R(I,1))
00090 VUS(I,3)=VUS(I,1)
00091 C*** CALCULATION OF CURVATURE TERM AND ROTOR AND STATOR LOSSES (STEP 4)
00092 C***
00093 DC 232 J=1,3
00094 DUM(I)=VUS(I,J)*R(I,J)
00095 RR(I)=R(I,J)
00096 CALL DERIV(N,RR,DUM,DER)
00097 DO 234 I=1,N
00098 DVUDR(I,J)=DER(I)
00099 232 CONTINUE
00100 DO 208 I=1,N
00101 LAMDA(I)=ATAN(R(I,3)-R(I,1))/(LR+LS))
00102 IF(TEST1)206,207,208
00103 C*** TEST1=POSITIVE MEANS FIRST ITERATION LOOP
00104 DO 215 I=1,N
00105 CRTERM(I)=CURV*(R(I,3)+R(I,1))/2.-R(I,2) /((LR+LS)/2.)*2*2.
00106 GO TO 216
00107 DO 216 I=1,N
00108 CRTERM(I)=0.
00109 IF(TEST1)218,218,219
00110 DC 631 I=1,N
00111 DUM(I)=WS(I,1)
00112 DUM1(I)=WS(I,2)
00113 DUM2(I)=WUS(I,1)
00114 DUM3(I)=WUS(I,2)
00115 DUM4(I)=BETA(I,1)
00116 DER(I)=BETA(I,2)
00117 RR(I)=MACHR(I,1)
00118 CALL LOSTP(-1,DUM,DUM1,DUM2,DUM3,DUM4,RR,DER,SIGR,GAMA,N)
00119 GO TO 220
00120 219 DO 221 I=1,N
00121 DPTS(I,1)=0.
00122

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C110 DO 209 I=1,N
C111 DO 209 J=1,N
C112 SS(I,2)=SS(I,1)-RG/CP*ALOG(1.-DD /PTS(I,1)*(HS(I,1)/HS(I,2))*
C113 1*(GAMA/(GAMA-1.)))
C114 PTS(I,2)=PTS(I,1)*(HS(I,2)/HS(I,1))*((GAMA/(GAMA-1.))-DD
C115 IF(TEST1)721,721,222
C116 DO 632 I=1,N
C117 DUM(I)=VS(I,2)
C118 DUM1(I)=VS(I,3)
C119 DUM2(I)=VUS(I,2)
C120 DUM3(I)=VUS(I,3)
C121 DUM4(I)=ALFA(I,2)
C122 RR(I)=ALFA(I,3)
C123 DER(I)=MACH(I,2) ,DUM,DUM1,DUM2,DUM3,DUM4,RR,DER,SIGS,GAMA,N)
C124 CALL LOSTP( 2)
C125 GO TO 223
C126 DO 224 I=1,N
C127 DPTS(I,2)=C
C128 DO 210 I=1,N
C129 DD=DPTS(I,2)
C130 SS(I,3)=SS(I,2)-RG/CP*ALOG((PTS(I,2)- DD )/PTS(I,2))
C131 PTS(I,3)=PTS(I,2)-DD
C132 C*****
C133 C*****
C134 C*****
C135 CALCULATION OF ENTROPY AND ENERGY GRADIENTS.CALCULATION OF FUNCT1-
C136 CNS F* AND G* (STEP 5).
C137 TEST1=-1
C138 DO 225 J=1,3
C139 DO 226 I=1,N
C140 DUM(I)=SS(I,J)
C141 RR(I)=RR(I,J)
C142 CALL DERIR(N,RR,DUM,DER)
C143 DO 227 I=1,N
C144 DSDRS(I,J)=DER(I)
C145 DO 228 I=1,N
C146 DUM(I)=HS(I,J)
C147 CALL DERIR(N,RR,DUM,DER)
C148 DO 229 I=1,N
C149 DHDRS(I,J)=DER(I)
C150 CCNT INUE
C151 DO 231 J=1,3
C152 DO 231 I=1,N
C153 F(I,J)=CRTERM(I)-1./COS(LAMDA(I))*2.*DSDRS(I,J)
C154 G(I,J)=2.*VUS(I,J)/R(I,J)*DVUDR(I,J)-2.*DHDRS(I,J)+(2.*HS(I,J))-VU
C155 1S(I,J)*2.*DSDRS(I,J)
C156 CRTERM(I)=-CRTERM(I)
C157 CCNT INUE
C158 CALCULATION OF THE INTEGRALS INVOLVED IN THE CALCULATION OF THE
C159 AXIAL VELOCITY DISTRIBUTION (STEP 6).
C160 DO 734 J=1,3
C161 DO 732 I=1,N
C162 DUM(I)=F(I,J)
C163 PR(I)=R(I,J)
C164 CALL SUMAT(N,DUM,RR,DUM1)
C165 DO 733 I=1,N
C166 FUNC1(I,J)=1./EXP(DUM1(I))
C167 DUM(I)=G(I,J)*EXP(DUM1(I))
C168 CALL SUMAT(N,DUM,RR,DUM1)
C169 DO 235 I=1,N
C170 FUNC2(I,J)=-FUNC1(I,J)*DUM1(I)
C171 CCNT INUE
C172 C*****
C173 C*****
C174 C*****
C175 START THE ITERATION FOR THE CALCULATION OF THE AXIAL VEL. DISTRIB.
C176 (STEP 6).
C177 DO 237 J=1,3
C178 DO 260 I=1,N
C179 DUM(I)=FUNC2(I,J)/FUNC1(I,J)
C180 A=AMINI(DUM(I),DUM(2),DUM(3),DUM(4),DUM(5),DUM(6),DUM(7),DUM(8),
C181 1DUM(9))
C182 IF(A)266,267,267
C183 DEB=1./21*SQRT(ABS(A))
C184 266

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C169      GOTO 268
C170      DER=0
C171      FIN=16.
C172      DE=1.
C173      NAL=0
C174      EPS=.0021
C175      CALL ITPN(DEB,FIN,DE,EPS,NAL,DEP,X1,X2,X3,F1,F2,NS,NN)
C176      IF(NS)301,302,303
C177      WRITE(6,106)
C178      STOP
C179      DO 236 I=1,N
C180      VAS(1,J)=SQRT(FUNC1(I,J)*X2**2+FUNC2(I,J))
C***
C***      CCNTINUITY CONSIDERATIONS (STEP 7)
C***
C181      VRS(I,J)=VAS(I,J)*TAN(LAMDAL(I))
C182      VS(I,J)=SQRT(VUS(I,J)**2+VAS(I,J)**2+VRS(I,J)**2)
C183      T(I,J)=(HS(I,J)-VS(I,J)**2/2.)*VREF**2/CP
C184      SOUND(I,J)=SQRT(GAMA*RG*T(I,J))/VREF
C185      MACH(I,J)=VS(I,J)/SOUND(I,J)
C186      STDEN(I,J)=PTS(I,J)*HATMS/HS(I,J)*(1.+(GAMA-1.)/2.*MACH(I,J)**2)**
      1/(1.-(GAMA))
C187      DUM(I)=2.*PI*STDEN(I,J)*VAS(I,J)*R(I,J)
C188      PR(I)=R(I,J)
C189      CALL SUMAT(N,DUM,PR,DUM1)
C190      E2=DUM1*(KB(J)-MSPLOS)
C191      GO TO 305
C192      DO 245 I=1,N
C193      Z(J)=MSFSL(I,J)=DUM1(I)
C194      237 CCNTINUE
C***
C***      CALCULATION OF THE NEW STREAMLINE POSITION (STEP 8)
C***
C195      DO 272 M=2,3
C196      I=-1
C197      I=I+1
C198      DC 271 J=1,3
C199      J1=I+J
C200      Z(J)=MSFSL(J1,M)
C201      W(J)=R(J1,M)
C202      J2=I+2
C203      SFSL=MSFSL(J2,J)*KB(1)/KB(M)
C204      CALL ITPO(3,SFSL,Z,W)
C205      PR(J2,M)=W(1)
C206      IF(I-N+3)274,275,275
C207      IF(I-N+3)274,275,275
C208      275 CCNTINUE
C209      272 CCNTINUE
C210      DO 273 J=2,3
C211      DO 277 I=2,N1
C212      PR(I)=R(I,J)-RRR(I,J)
C213      277 CCNTINUE
C***
C***      CALCULATION OF THE ERROR (STEP 9)
C***
C214      B=L
C215      DO 276 I=2,N1
C216      B=B+(RR(I))**2
C217      ERROR(J-1)=SQRT(B)
C218      DO 281 I=2,N1
C219      R(I,J)=R(I,J)-WFACT*RR(I)
C220      281 CCNTINUE
C221      DO 276 J=2,3
C222      DO 270 I=1,N
C223      RCTS(I,J)=PTS(I,J)*CP/(RG*H(I,J))*PATM/ROATM
C224      270 CCNTINUE
C225      276 CCNTINUE
C***
C***      SCME ADDITIONAL CALCULATIONS (STEP 9)
C***
C226      DO 381 J=1,3
C227      DO 382 I=1,N
C228      S(I,J)=SS(I,J)*CP
C229      RCT(I,J)=RCTS(I,J)*ROATM
C230      VU(I,J)=VUS(I,J)*VREF
C231      VA(I,J)=VAS(I,J)*VREF
C232      VR(I,J)=VRS(I,J)*VREF

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FORTRAN IV G LEVEL 18      MAIN      DATE = 71251      17/06/32
0349      FORMAT(/,20X,'STAGE',/ ,3X,'STATION',4X,'ETA T-T',8X,'ETA S-S',12X,
0350      1,'DPSST',//,
0351      WRITE(6,940)(I,HSTTT(I),HSTSS(I),DPSST(I),I=1,N)
0352      FORMAT(3X,12,3X,1X,E15.8,1X,E15.8)
0353      WRITE(6,941,HSTTT8,HSTSS8)
0354      FORMAT(7,1X,'MASS AVERAGED QUANTITIES',//,5X' HSTTT8',8X,'HSTSS8',
0355      1/2(1X,E15.8))
0356      CONTINUE
0357      FORMAT(4E15.8)
0358      FORMAT(313)
0359      FORMAT(2X,'ERROR',/ )
0360      FORMAT(2X,'STATION '12//,8X,'R',15X,'PT',15X,'ROT',15X,'H ',15X,'S'
0361      1,15X,'DH',15X,'T',/ )
0362      FORMAT(7(1X,E15.8))
0363      FORMAT(//,8X,'R',15X,'V',15X,'VA',15X,'VU',15X,'VR',15X,'RO',15X,'MA
0364      1CH',/ )
0365      FCFORMAT(7(1X,E15.8))
0366      STOP
0367      END

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FORTRAN IV G LEVEL 18          LOSTP          DATE = 71251          17/C6/32

SUBROUTINE LOSTP(ITES2,V1,V2,VU1,VU2,A1,A2,AMACH,SIGM,GAMA,N)
COMMON R(11,3),
      DFAC(11,2),PTS(11,3),PS(11,3),DPS(11,2)
DIMENSION V1(11),V2(11),VU1(11),VU2(11),A1(11),A2(11),AMACH(11),
      ISIGM(11)
PI=3.141593
IF(ITES2)1,1,2

C***
C***
C***
C***
1 J=1
  CNST=0.228
  GO TO 3
2 J=2
  CNST=0.357
  DO 4 I=1,N
    SIGM=SIGM(I)
    DFAC(I,J)=1.-V2(I)/V1(I)+(R(I,J)*VU1(I)-R(I,J+1)*VU2(I))/(SIGMA*
1(R(I,J)+R(I,J+1))*V1(I))
    DFAC(I,J)=ABS(DFAC(I,J))
    RR=(R(N,J+1)-R(1,J+1))/(R(N,J+1)-R(1,J+1))
    DPS(I,J)=2.*SIGM/COS(A2(I)/57.29578)*(J).C04+(.0639*(DFAC(I,J)+C.1
1)*2.91+CNST*DFAC(I,J)*2.02*(1.-RR)*3.77)
    IF(A2(I))1,45,IGOTO 5
    DPS(I,J)=DPS(I,J)*COS(A2(I)/57.29578)*SQR(2.)*(1.-PI/4.+PI*A2(I)
1/180.)
5 DELN1=.625*(A1(I)-A2(I))/SIGMA
  AMACH=AMACH(I)
  IF(AMACH(I).GT.1.)GO TO 6
  AM=1./AM
  ITES3=1
  AMSU=1.055+.03395*DELN1+1.086*(AM-1.)*1.372
  AMM=(AMACH(I)+AMSU)/2.
  IF(AMM.LT.1.)AND. ITES3.EQ.1)GO TO 7
  IF(AMM.GT.1.)AND. ITES3.EQ.1)GO TO 10
  GO TO 9
10 AMM=1.
  Z1=((GAMA+1.)*AMM*2/((GAMA-1.)*AMM**2+.2.))*((GAMA/(GAMA-1.))
  Z2=((GAMA+1.)/2.*GAMA*AMM**2-GAMA+1.))*((1.)/(GAMA-1.))
  Z3=(1.-(GAMA-1.)/2.*AMM**2))*((GAMA/(GAMA-1.))
  DPSSH=(1.-Z1*Z2)/(1.-1./Z3)
  GO TO 8
7 DPSSH=)
8 DPS(I,J)=DPS(I,J)+DPSSH
4 DPS(I,J)=DPS(I,J)*(PTS(I,J)-PS(I,J))
  RETURN
END

```

```

0001 SUBROUTINE SUMAT(N,Y,X,SUM)
0002 DIMENSION Y(1),X(1),SUM(1),S(3),F(3)
0003 SUM(1)=0.
0004 N1=N-2
0005 DO 1 I=1,N1,2
0006   SUM(I+2)=SUM(I)+TEGP(X(I),X(I+1),X(I+2),Y(I),Y(I+1),Y(I+2))
0007 DC 2 I=2,N1,2
0008   J=1,3
0009   J1=I-3+2*J
0010   S(J)=X(J1)
0011   F(J)=SUM(J1)
0012   FF=X(I)
0013   CALL INTPD(3,FF,S,F)
0014   SUM(I)=F(1)
0015   DO 4 J=1,3
0016     J1=N+2-J-6
0017     S(J)=X(J1)
0018     F(J)=SUM(J1)
0019     FF=X(N-1)
0020     CALL INTPD(3,FF,S,F)
0021     SUM(N-1)=F(1)
0022   RETURN
0023 END

```

```

0001 SUBROUTINE INTPO(NI,XI,X,F)
0002 DIMENSION X(1),F(1)
0003 J=1
0004 NP=NI
0005 NP=NP-1
0006 J=J+1
0007 DO 2 K=1,NP
0008 I=K+J
0009 F(K)=(F(K)*(X(I)-XI)+F(K+1))*(XI-X(K))/(X(I)-X(K))
0010 IF(NP-1) 3,3,1
0011 3 RETURN
0012 END

```



```

0001 SUBROUTINE DERIR(N,S,W,DER)
0002 DIMENSION X(5),Y(5),XX(5),YY(5),F1(4),F2(3),F3(2),S(1),W(1),DER(1)
0003 DO 80 I=1,2
0004 XX(I)=S(I)
0005 YY(I)=W(I)
0006 M=0
0007 K=0
0008 DO 10 I=3,5
0009 L=I-K-1
0010 XX(I)=S(L)
0011 YY(I)=W(L)
0012 10 M=M+1
0013 M1=M-K+1
0014 X(I)=XX(M1)
0015 Y(I)=YY(M1)
0016 IF(M1-1)1,2,1
0017 1 DC 20 I=2,M1
0018 J=I-1
0019 X(J)=XX(J)
0020 Y(J)=YY(J)
0021 IF(M1-5)3,4,4
0022 3 DC 30 I=M1,4
0023 J=I+1
0024 X(J)=XX(J)
0025 Y(J)=YY(J)
0026 IF(I=1)4
0027 F1(I)=(Y(I)-Y(I+1))/(X(I)-X(I+1))
0028 DO 50 I=1,3
0029 F2(I)=(F1(I)-F1(I+1))/(X(I)-X(I+2))
0030 DC 60 I=1,2
0031 F3(I)=(F2(I)-F2(I+1))/(X(I)-X(I+3))
0032 F4=(F3(1)-F3(2))/(X(1)-X(5))
0033 DER(M)=F1(1)*(X(1)-X(2))+F2(1)*(X(1)-X(3))+F3(1)*(X(1)-X(4))+F4
0034 1-X(2))*(X(1)-X(3))*(X(1)-X(4))*F4
0035 IF(M-2)6,6,7
0036 IF(M-N+2)8,6,6
0037 IF(M-N)5,1,5,15
0038 DC 70 I=1,2,15
0039 XX(I)=X(I+1)
0040 YY(I)=Y(I+1)
0041 70 GOTO 25
0042 15 RETURN
0043 END

```



```

0001 SUBROUTINE ITERN(DER,FIN,DE,EPS,NAL,DEP,X1,X2,X3,F1,F2,NS,NN)
0002 IF(NAL) 16,16,17
0003 NS=0
0004 NN=0
0005 NAL=1
0006 DEP=DE
0007 F2=0
0008 X2=DEB-DE
0009 F1=F2
0010 X1=X2
0011 X2=X2+DEP
0012 IF(X2-FIN)15,15,12
0013 NS=1
0014 GC TO 15
0015 IF(NN)7,10,4
0016 IF(ABS(F2-EPS))11,11,13
0017 IF(F1-F2)5,11,5
0018 IF(F1-F2)6,11,1
0019 X3=X2
0020 NN=1
0021 DEP=1/2*DEP/(F1-F2)
0022 GOTO 2
0023 IF(F1-F2)8,11,9
0024 DEP=(X1-X2)/10.
0025 GOTO 10
0026 DEP=(X3-X2)/10.
0027 NN=1
0028 GOTO 1
0029 NS=1
0030 RETURN
0031 15 END

```

FORTRAN IV G LEVEL 18 AVER DATE = 71251 PAGE 0001
 0001 SUBROUTINE AVER(R,VA,X,RQ,Q,BF,AV,N)
 0002 DIMENSION R(1),VA(1),RO(1),X(1)
 0003 DC 1 I=1,N
 0004 1 X(I)=2.*3.1415927*R(I)*VA(I)*RO(I)*X(I)
 0005 AV=Q.
 0006 N1=N-2
 0007 DO 2 I=1,N1,2
 0008 2 AV=AV+TEGP(R(I),R(I+1),R(I+2),X(I),X(I+1),X(I+2))
 0009 AV=AV*BF/Q
 0010 RETURN
 0011 END

17/06/32

DATE = 71251

```

FORTRAN IV G LEVEL 18      TEGP
0001      FUNCTION      TEGP(X1,X2,X3,Y1,Y2,Y3)
0002      T1=4.*X2-X3-3.*X1
0003      T2= 4.*(X3-X1)
0004      T3=3.*X3+X1-4.*X2
0005      TEGP=(T1*Y1+T2*Y2+T3*Y3)/6.
0006      RETURN
0007      END

```

INITIAL DATA

RH1	RH2	RH3	RI1	RI2	RI3
.89999998E 05	.89999998E 00	.89999998E 00	.15000000E 01	.15000000E 01	.15000000E 01
LS	LR	RPM	RG	CURV	GAMA
.173333329E 00	.17333329E 00	.22900000E 04	.17156299E 04	.40000000E 01	.13999996E 01
KB1	KB2	KB3	PATM	TATM	RO ATM
.10000000E 01	.9649997E 00	.94000000E 00	.21152300E 04	.52000000E 03	.23709950E-02
MASS FLOW					
.24516134E 01					
S1	RF	OH	H1		
.0	.50000000E 00	.30295758E 05	.31224440E 07		
.0	.50000000E 00	.30295758E 05	.31224440E 07		
.0	.50000000E 00	.30295758E 05	.31224440E 07		
.0	.50000000E 00	.30295758E 05	.31224440E 07		
.0	.50000000E 00	.30295758E 05	.31224440E 07		
.0	.50000000E 00	.30295758E 05	.31224440E 07		
.0	.50000000E 00	.30295758E 05	.31224440E 07		
.0	.50000000E 00	.30295758E 05	.31224440E 07		

ITERATION

ERROR 1

ERROR 2

C-29635515E-01
 C-12412686E-01
 C-32616434E-02
 C-13270945E-02
 C-14270914E-02
 C-01357701E-03
 C-01577621E-03
 C-063861324E-03
 C-56216074E-03
 C-49772596E-03
 C-43983618E-03
 C-38991333E-03
 C-3425451E-03
 C-03080760E-03
 C-27142046E-03
 C-24246731E-03
 C-21374314E-03
 C-19154320E-03
 C-17210366E-03

STATION 1

DIMENSIONLESS QUANTITIES

P*	PT*	PS*	ROT*	RO*	H*	S*	TS*
75000000E-01	10000000E-01	095850873E-00	099999988E-00	097018385E-00	037705460E-02	00000000E-00	0987966475E-00
81250000E-01	10000000E-01	095924561E-00	099999988E-00	097070688E-00	037705460E-02	00000000E-00	0988178375E-00
87499994E-01	10000000E-01	096020164E-00	099999988E-00	097145104E-00	037705460E-02	00000000E-00	098848075E-00
93749988E-01	10000000E-01	096150047E-00	099999988E-00	097241399E-00	037705460E-02	00000000E-00	09887092E-00
99999982E-01	10000000E-01	096303018E-00	099999988E-00	097349399E-00	037705460E-02	00000000E-00	098931038E-00
10624990E-01	10000000E-01	096486348E-00	099999988E-00	097477412E-00	037705460E-02	00000000E-00	098983126E-00
11249981E-01	10000000E-01	096645266E-00	099999988E-00	097592688E-00	037705460E-02	00000000E-00	099029725E-00
11874971E-01	10000000E-01	096793141E-00	099999988E-00	097793146E-00	037705460E-02	00000000E-00	099111468E-00
12500000E-01	10000000E-01	096924967E-00	099999988E-00	097793146E-00	037705460E-02	00000000E-00	099111468E-00

ALFA	MACH	VR*	VR*	BETA
079122433E-01	02479399E-00	038460903E-03	033260437E-02	033260437E-02
011019778E-01	02479399E-00	027124783E-03	0335623544E-02	0335623544E-02
017321189E-01	02479399E-00	037243378E-03	0339144714E-02	0339144714E-02
020605804E-01	02479399E-00	037185153E-03	0341408890E-02	0341408890E-02
0224101105E-01	02479399E-00	020472135E-02	0343823376E-02	0343823376E-02
027762126E-01	02479399E-00	022553111E-02	0346433762E-02	0346433762E-02
031635330E-01	02479399E-00	015242666E-02	0349276947E-02	0349276947E-02
035787323E-01	02479399E-00	022117118E-02	035000000E-02	035000000E-02

BETA

MACH R

WU*

W*

PT	PS	ROT	RO	H	TS
02115230E-04	020290039E-04	023709945E-02	023003009E-02	0224444E-07	051374170E-03
02115230E-04	020290039E-04	023709945E-02	023003009E-02	0224444E-07	051380278E-03
02115230E-04	020290039E-04	023709945E-02	023003009E-02	0224444E-07	051401001E-03
02115230E-04	020290039E-04	023709945E-02	023003009E-02	0224444E-07	051424189E-03
02115230E-04	020290039E-04	023709945E-02	023003009E-02	0224444E-07	0514444141E-03
02115230E-04	020290039E-04	023709945E-02	023003009E-02	0224444E-07	051471216E-03
02115230E-04	020290039E-04	023709945E-02	023003009E-02	0224444E-07	051493459E-03
02115230E-04	020290039E-04	023709945E-02	023003009E-02	0224444E-07	051517480E-03
02115230E-04	020290039E-04	023709945E-02	023003009E-02	0224444E-07	051537964E-03

DIMENSIONAL QUANTITIES

P*	PT*	PS*	ROT*	RO*	H*	S*	TS*
75000000E-01	10000000E-01	095850873E-00	099999988E-00	097018385E-00	037705460E-02	00000000E-00	0987966475E-00
81250000E-01	10000000E-01	095924561E-00	099999988E-00	097070688E-00	037705460E-02	00000000E-00	0988178375E-00
87499994E-01	10000000E-01	096020164E-00	099999988E-00	097145104E-00	037705460E-02	00000000E-00	098848075E-00
93749988E-01	10000000E-01	096150047E-00	099999988E-00	097241399E-00	037705460E-02	00000000E-00	09887092E-00
99999982E-01	10000000E-01	096303018E-00	099999988E-00	097349399E-00	037705460E-02	00000000E-00	098931038E-00
10624990E-01	10000000E-01	096486348E-00	099999988E-00	097477412E-00	037705460E-02	00000000E-00	098983126E-00
11249981E-01	10000000E-01	096645266E-00	099999988E-00	097592688E-00	037705460E-02	00000000E-00	099029725E-00
11874971E-01	10000000E-01	096793141E-00	099999988E-00	097793146E-00	037705460E-02	00000000E-00	099111468E-00
12500000E-01	10000000E-01	096924967E-00	099999988E-00	097793146E-00	037705460E-02	00000000E-00	099111468E-00

DIMENSIONLESS QUANTITIES									

P	U	W	MU	VA	VR	ALFA	MACH	TS	
R*	PT*	PS*	ROT*	RD*	H*	S*	TS*		
75.000006	0.1322978E-01	0.98647034E-00	0.10221786E-01	0.9866418E-00	0.3871289E-02	0.62815147E-03	0.99674165E-00		
81.254514E-01	0.1322978E-01	0.98725206E-00	0.10222503E-01	0.99031715E-00	0.3871289E-02	0.57421415E-03	0.9991254E-00		
87.1254514E-01	0.1322978E-01	0.98737316E-00	0.10222503E-01	0.99115470E-00	0.3871289E-02	0.53690743E-03	0.99719942E-00		
93.7432795E-01	0.1322978E-01	0.98748009E-00	0.10222503E-01	0.99211820E-00	0.3871289E-02	0.51920724E-03	0.9958911E-00		
99.6672995E-01	0.1322978E-01	0.99143738E-00	0.10222503E-01	0.99333982E-00	0.3871289E-02	0.52902274E-03	0.9907310E-00		
104.159462E-01	0.1322978E-01	0.99135734E-00	0.10222503E-01	0.99575789E-00	0.3871289E-02	0.57544800E-03	0.99664310E-00		
116.74481E-01	0.1322978E-01	0.99253556E-00	0.10221978E-01	0.99575789E-00	0.3871289E-02	0.67930087E-03	0.99926287E-00		
125.000006	0.1322978E-01	0.99800462E-00	0.10199226E-01	0.99773167E-00	0.3871289E-02	0.87994384E-03	0.99939866E-00		
149.99990E	0.1322978E-01	0.99800462E-00	0.10199226E-01	0.99773167E-00	0.3871289E-02	1.12584946E-02	0.10306866E-01		

DIMENSIONAL QUANTITIES									

R	PT	PS	RQT	R0	H	TS			
899999992E	0.2183124E-04	0.20866116E-04	0.24235803E-02	0.234655599E-02	0.31527330E-07	0.51830566E-03			
97517395E	0.2183124E-04	0.20866116E-04	0.24240371E-02	0.23480132E-02	0.31527330E-07	0.51839453E-03			
10501499E	0.2183124E-04	0.20866116E-04	0.24244353E-02	0.23500044E-02	0.31527330E-07	0.51844370E-03			
11249199E	0.2183124E-04	0.20866116E-04	0.24244503E-02	0.23524493E-02	0.31527330E-07	0.51849805E-03			
11996169E	0.2183124E-04	0.20866116E-04	0.24244503E-02	0.23524493E-02	0.31527330E-07	0.51849805E-03			
12733124E	0.2183124E-04	0.20866116E-04	0.24244503E-02	0.23524493E-02	0.31527330E-07	0.51849805E-03			
13487349E	0.2183124E-04	0.20866116E-04	0.24244503E-02	0.23524493E-02	0.31527330E-07	0.51849805E-03			
14244894E	0.2183124E-04	0.20866116E-04	0.24244503E-02	0.23524493E-02	0.31527330E-07	0.51849805E-03			
14999990E	0.2183124E-04	0.20866116E-04	0.24244503E-02	0.23524493E-02	0.31527330E-07	0.51849805E-03			

STATION 3

ROTOR AND STATOR DATA

STATION	LOSS COEFF.	D F	DPTH	DPSR	ETAR
1	0.78478782E-03	0.31194323E-00	0.33584595E-01	0.11060238E-01	0.97744977E-00
2	0.77975797E-03	0.32267993E-00	0.33589363E-01	0.12517237E-01	0.97754657E-00
3	0.77212648E-03	0.32943541E-00	0.33595992E-01	0.13426700E-01	0.97770111E-00
4	0.77148764E-03	0.33202606E-00	0.33591270E-01	0.13777793E-01	0.97764331E-00
5	0.83391694E-03	0.33467168E-00	0.33535004E-01	0.13901711E-01	0.97594965E-00
6	0.93363120E-03	0.33467168E-00	0.33415794E-01	0.13457716E-01	0.97281065E-00
7	0.13375191E-02	0.34270734E-00	0.33131599E-01	0.13694108E-01	0.96231580E-00
8	0.13709371E-02	0.35941404E-00	0.32559395E-01	0.14448822E-01	0.94788289E-00
9	0.29315238E-02	0.38496536E-00	0.31337874E-01	0.15405178E-01	0.91563638E-00

MASS AVERAGED QUANTITIES

PTBAR1 PSBAR1 PTBAR2 PSBAR2 DPTBR DPSR ETABAR
 0.10332413E-01 0.463356259E-00 0.10332413E-01 0.97713470E-00 0.33245191E-01 0.96764785E-00

STATION	LOSS COEFF.	D F	DPSS	ETAS	ETAS
1	0.14867329E-02	0.32745349E-00	0.16901374E-01	0.92298985E-00	0.92298985E-00
2	0.12963191E-02	0.32451871E-00	0.15499175E-01	0.92633531E-00	0.92633531E-00
3	0.11701181E-02	0.32653571E-00	0.14685452E-01	0.92958331E-00	0.92958331E-00
4	0.11057258E-02	0.33441454E-00	0.14317334E-01	0.93227943E-00	0.93227943E-00
5	0.11793136E-02	0.34597123E-00	0.14445484E-01	0.93341947E-00	0.93341947E-00
6	0.11280926E-02	0.36223343E-00	0.14336149E-01	0.93266302E-00	0.93266302E-00
7	0.11862707E-02	0.37931567E-00	0.14906704E-01	0.92725354E-00	0.92725354E-00
8	0.13709285E-02	0.39514697E-00	0.14366329E-01	0.91600258E-00	0.91600258E-00
9	0.18144589E-02	0.41171594E-00	0.13349771E-01	0.89547426E-00	0.89547426E-00

MASS AVERAGED QUANTITIES

PTBAR2 PSBAR2 PTBAR3 PSBAR3 DPTBR DPSR ETABAR
 0.10332413E-01 0.463356259E-00 0.97713470E-00 0.9191004E-00 0.92616859E-00

STATION	ETA T-T	ETA S-S	DPSSI
1	0.93462372E-00	0.95337048E-00	0.27961612E-01
2	0.94228550E-00	0.95903885E-00	0.28016448E-01
3	0.94410837E-00	0.96300483E-00	0.28115171E-01
4	0.94589883E-00	0.96515970E-00	0.28197527E-01
5	0.94493103E-00	0.96597725E-00	0.28347194E-01
6	0.94674351E-00	0.96462250E-00	0.28393865E-01
7	0.92725233E-00	0.96234310E-00	0.28600812E-01
8	0.90844423E-00	0.95880314E-00	0.28815150E-01
9	0.86915070E-00	0.95336289E-00	0.28754950E-01

MASS AVERAGED QUANTITIES

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Code 57
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Rhode-St.-Genese
Belgium

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13. ABSTRACT A computer program is presented to determine the three-dimensional flow conditions in an axial flow compressor stage. Entropy and energy gradients are taken into account as well as the radial shift and the curvatures of the axisymmetric stream surfaces. - The program can be used at elevated Mach numbers since shock losses and compressibility effects are included. It represents an extension of work done for a research program to investigate the tip clearance effects in a three-stage compressor, supported by: Naval Air Systems Command, Code 310, AIRTASK No. A310310A/551A/1 RO10-03-010.			

KEY WORDS

LINK A

LINK B

LINK C

ROLE

WT

ROLE

WT

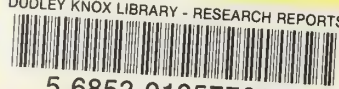
ROLE

WT

Axial compressor stage
 Computer Program
 Three-Dimensional Flow conditions
 Entropy and Energy Gradients

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